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# Assessment of NASA Dual Microstructure Heat Treatment Method Utilizing Ladish SuperCooler™ Cooling Technology

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February 2005

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# Assessment of NASA Dual Microstructure Heat Treatment Method Utilizing Ladish SuperCooler™ Cooling Technology

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## Background

NASA Glenn Research Center has developed and patented (Patent No. 6,660,110) a new method to produce dual microstructure disks having a coarse grain rim and a fine grain web and bore. The process utilizes specially designed heat treat fixtures that enable conventional batch type heat treat processing with existing furnace facilities. This process is called Dual Microstructure Heat Treatment (DMHT).

Allison Advanced Development Company (AADC) conducted a trade study to assess the impact of DMHT technology on superalloy disks for an advanced turbofan engine design for subsonic commercial regional aircraft. They concluded that for the baseline HPT disk, above 1325 °F rim temperature the dual microstructure enabled a lower weight disk (ref 1).

NASA, working closely with Ladish, has successfully demonstrated DMHT processing on small generic disks produced from alloy ME209 (refs. 2 to 4). A further Ladish/NASA collaborative effort successfully demonstrated the DMHT technology on multiple piece furnace batches on an actual production shape, the Rolls-Royce AE2100 stage 3 disk shape (ref 5).

Pratt & Whitney assessed the DMHT process on a rather complicated high pressure turbine disk shape, and compared against its own patented and production implemented Dual Property Heat Treat (DPHT) process method (Patent No. 5,312,497) (ref 6). The technical results of the lower cost DMHT were comparable to those produced by the DPHT process. However, P&W did mention some concerns with the “transient” nature of the process and mentioned more work was required to demonstrate process robustness.

The heat treatment approaches for prior DMHT efforts typically involved oil quenching. In one approach, the disk would be slow cooled from the DMHT conversion operation that would preferential coarsen the rim grain size, then subsequently be given a full uniform temperature sub-solvus solution followed by an oil quench. In another approach, the disk would be directly oil quenched from the DMHT conversion operation after rapid removal of the insulation and heat sinks. For most of the advanced P/M nickel-base alloys a more moderate cooling practice would be preferred/required, e.g., a rapid air cool. The purpose of this investigation is to integrate and demonstrate the NASA DMHT method with Ladish SuperCooler™ cooling practice.

## Summary

The intent of this investigation was to demonstrate the NASA DMHT method with a tailored Ladish SuperCool™ cooling method on a Rolls-Royce AE2100, stage 3 disk shape. One disk each of two alloys, LSHR and ME3, were successfully converted as shown by macrostructure.

DMHT heating time selection and cooling rate was aided by finite element modeling analysis. Residual stresses were also predicted and reported.

Detailed microstructural analysis was performed by NASA and included in this report. Mechanical property characterization, also planned by NASA, is incomplete at this time and not part of this report.

## Material Investigated

### Alloy ME209

Customer supplied as a single machined 9¼ in. diameter mult. Ladish identified this mult as XP005D serial 8.

### Alloy LSHR

Customer supplied as a single machined 6½ in. diameter mult. Ladish identified this mult as XP005D, serial 9.

## Forge Description

Billet multis were single step isothermally forged into EP017 finish dies. Forge parameters were selected to facilitate metal flow and post forge supersolvus solution heat treat response. Figure 1 shows a representative forging. This forging is approximately 14 inches in diameter.

## Heat Treat Description and Results

### Heat Treat Description

The heat treatment was performed utilizing Ladish SuperCooler™ facility, shown in figure 2. Both disks (ME209, serial 8 and LSHR, serial 9) were given an initial solution treatment at 2075 °F for 2 hours at temperature, followed by an air cool. Prior to the subsequent DMHT heat treatment, the two forgings were each fitted with top and bottom steel heat sinks and thermal insulation hardware (fig. 3). The hardware is similar to hardware utilized for past NASA/Ladish DMHT investigations (NASA Contracts C80000A and C74682A). Simple hardware design changes were incorporated to enable automated robotic handling; placement of entire assembly into furnace, transfer from furnace to cooling fixture, and removal of top hardware immediately



Figure 1.—Program Forging Configuration.



Figure 2.—Ladish SuperCooler™ Facility.

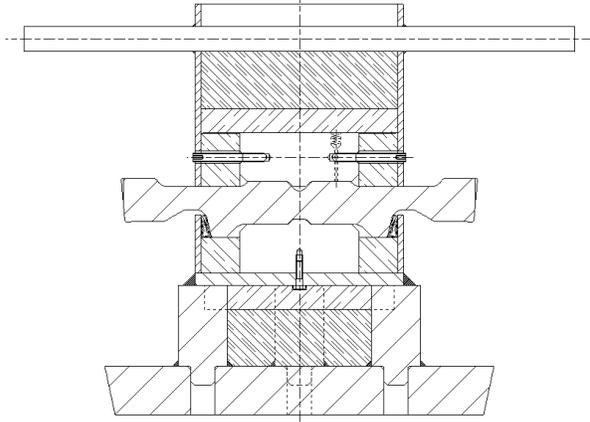


Figure 3.—DMHT Setup Schematic.



Figure 4.—Disk top-side insulation assembly.



Figure 5.—Disk bottom-side insulation components.

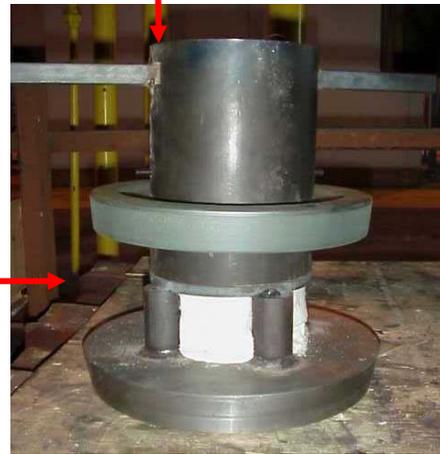


Figure 6.—DMHT Setup, serial 8.

prior to SuperCooler™ cooling. Figure 3 shows the arrangement of components as a schematic for this experiment. Figures 4 and 5 show photographs of the top and bottom insulation packages during assembly. Figure 6 shows a photograph of serial 8 after full assembly prior to DMHT furnace conversion.

The two disk assemblies (serials 8 and 9) were each separately placed directly into a furnace operating at the super-solvus temperature of 2175 °F ( $\gamma'$  solvus is approximately 2115 °F for both ME209 and LSHR alloys). Serial 8 was held in the furnace for a total time of 70 minutes; whereas, serial 9 was held in the furnace for a total time of 55 minutes. After heating each part for the specified furnace time, parts were transferred from furnace to the SuperCooler™ cooling station with automated robotic handling equipment. The transfer time was approximately 70 seconds for each disk (furnace door cracking open to initiation of air blow cycle). The parts were “supercooled” for 10 minutes, to a disk temperature well below 1000 °F, in accordance with approved cooling plan (see Modeling Support).

Process variables; disk insulation setup, furnace exposure, transfer into furnace, transfer from furnace to cooling station, and cooling air are well controlled variables and should be quite reproducible from piece-to-piece and run-to-run.

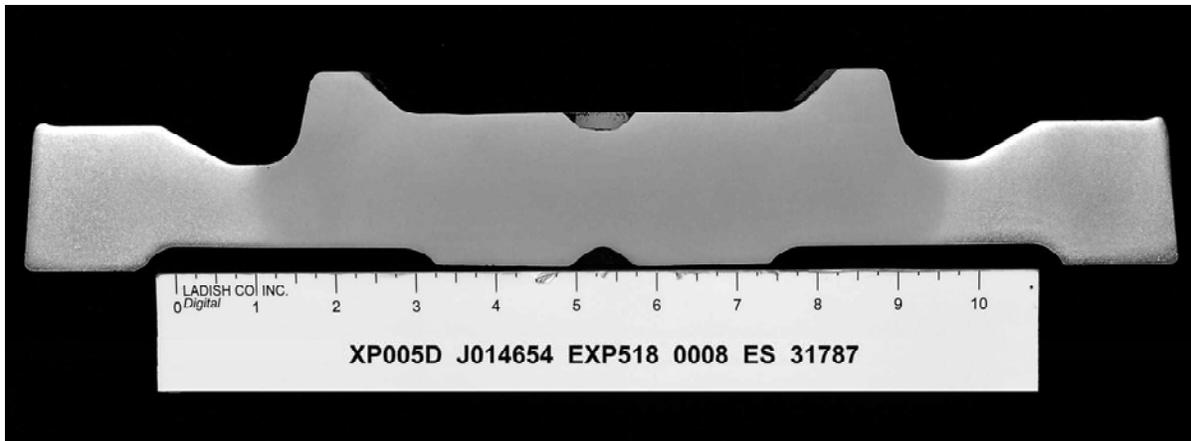


Figure 7.—Full radial macrostructure, serial 8.

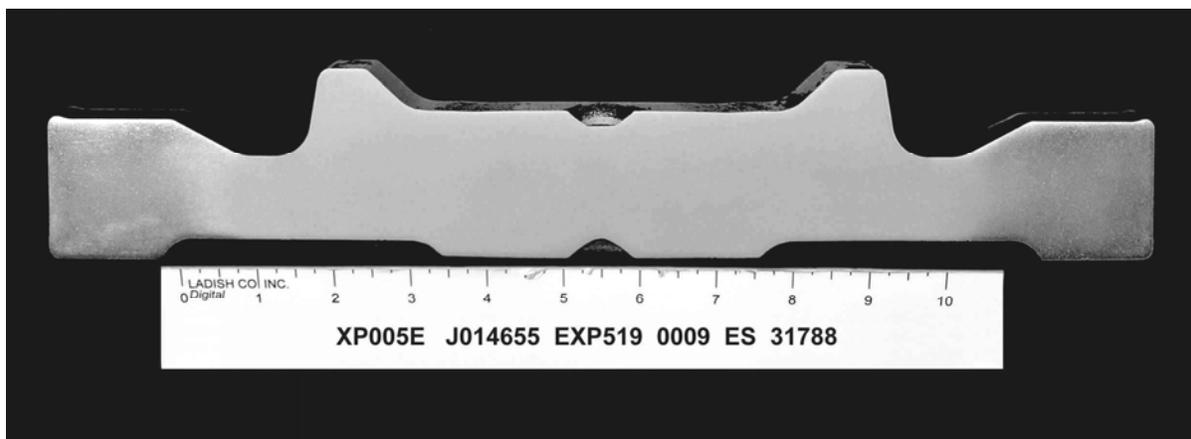


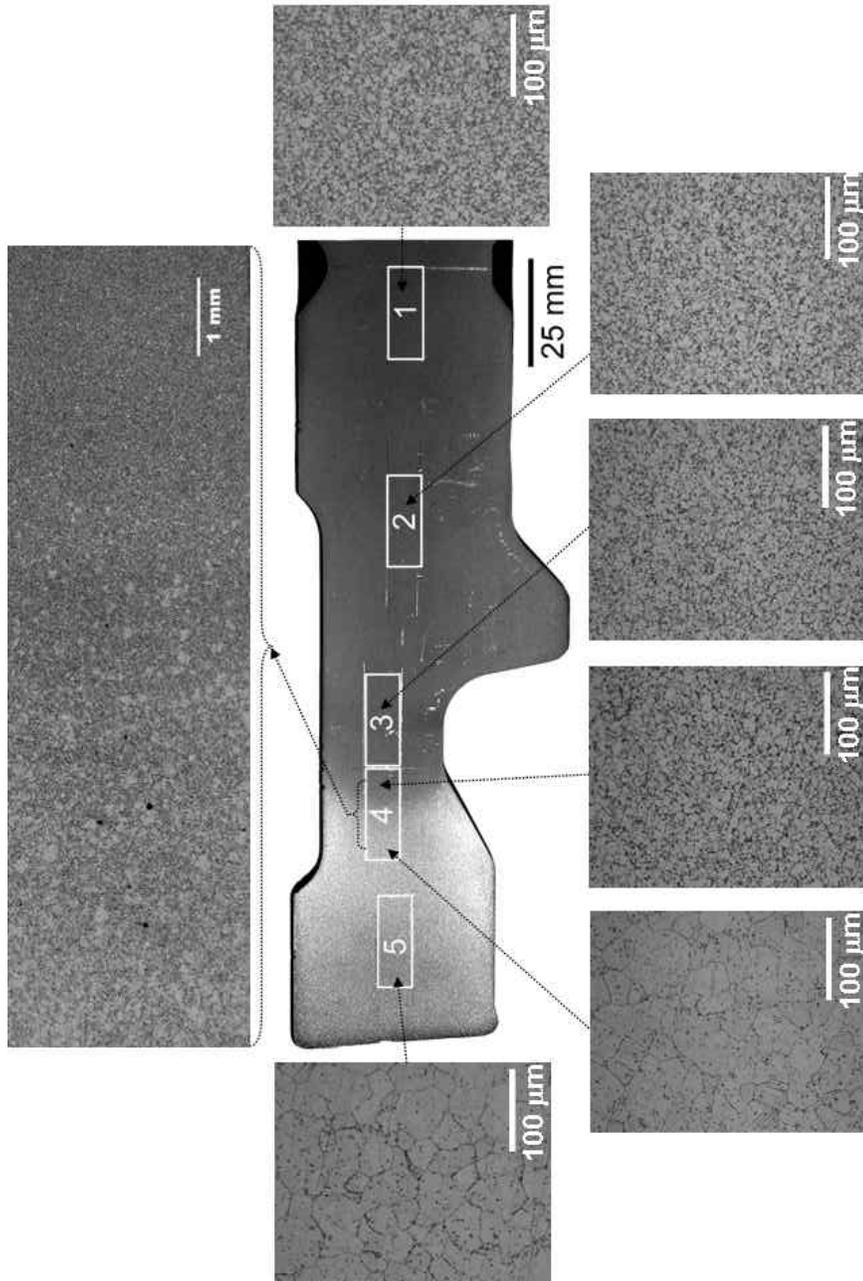
Figure 8.—Full radial macrostructure, serial 9.

### **Cross Sectional Macrostructural Review**

A full radial cross sectional slice was removed from both serials and etched to reveal macrostructure (figs. 7 and 8). The depths of coarsening were measured at approximately 2.8 in. from the forging rim at midthickness for serial 8 (70 minute furnace exposure) and 2.2 in. from the forging rim at midthickness for serial 9 (55 minute furnace exposure). The depths of coarsening were consistent at 0° and 180° for both pieces.

### **Microstructural Review**

NASA performed a detailed microstructural review on the serial 9 (LSHR) as depicted on figure 9.



Distance from bore (inch)	ASTM Grain Size
0.38	10.6
2.34	10.7
3.90	10.8
4.46	11
4.78	9.9
5.35	6.1
6.26	6.3

**LSHR DMHT Transition Zone Microstructure**

Figure 9.—Detailed microstructural review and analyses, serial 9.

# Modeling Support (ME3 Thermophysical Data was Used for all Simulations)

## DMHT Solution Heating Prediction

Ladish performed FEA modeling to predict the heating response and temperature distribution during heating for the DMHT process step. Figure 10 shows the simulated temperature distribution after 60 minutes exposure in a 2175 °F furnace. Knowing that ME3  $\gamma'$  solvus is approximately 2115F and expecting that grain coarsening occurs abruptly above this temperature, this model predicts that a 60 minute exposure would reflect a coarsened depth to approximately 3.5 in. distance from forging centerline. Based on past experience on same alloy and disk shape (ref. 5) it was felt that this simulation over estimated the depth of grain coarsening.

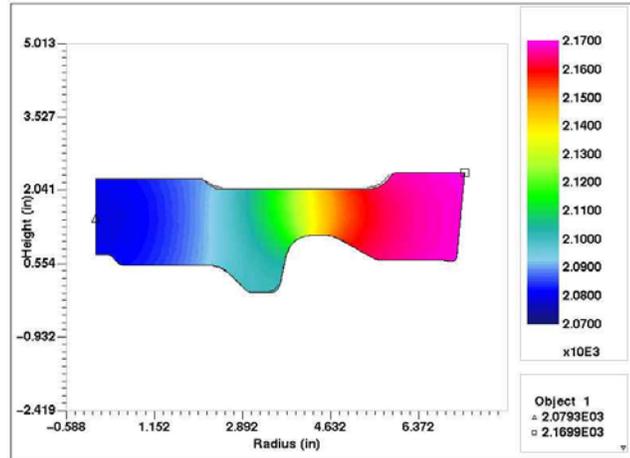


Figure 10.—Temperature (F) simulation at the end of 60 minutes within 2175 Furnace.

## DMHT Cooling Prediction

The air blow setting plan was based on NASA's desire for a relatively fast-cooling bore and slow-cooling rim. Figure 11a shows the average cooling rate for the subject disk (2100 to 1600 °F range) during SuperCool™ cooling. Figure 11b shows the temperature distribution after transfer from furnace immediately prior to initiating the SuperCool™ cooling. NASA was pleased with the predicted cooling rates and approved the corresponding cooling approach.

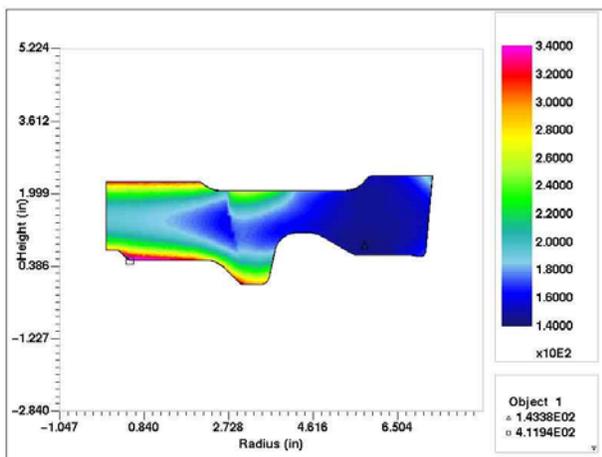


Figure 11a.—Simulation; average cooling rate (f/min) between 2100 and 1600 °F.

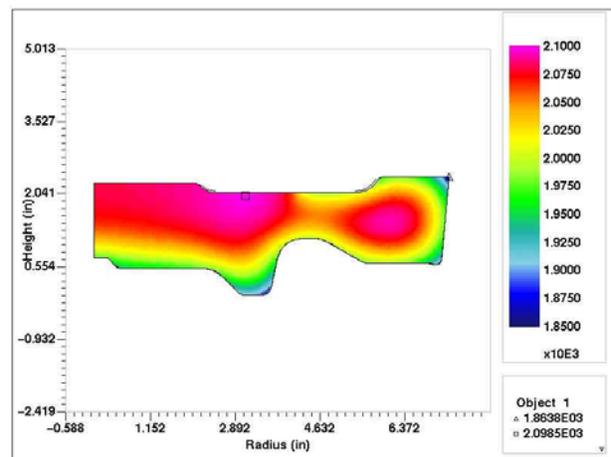


Figure 11b.—Simulation; disk temperature profile immediately prior to SuperCool™.

## Residual Stress Prediction

Figure 12 shows the radial, axial and hoop residual stress predictions. Supersolvus and subsolvus ME3 thermo-physical data was used in the simulation.

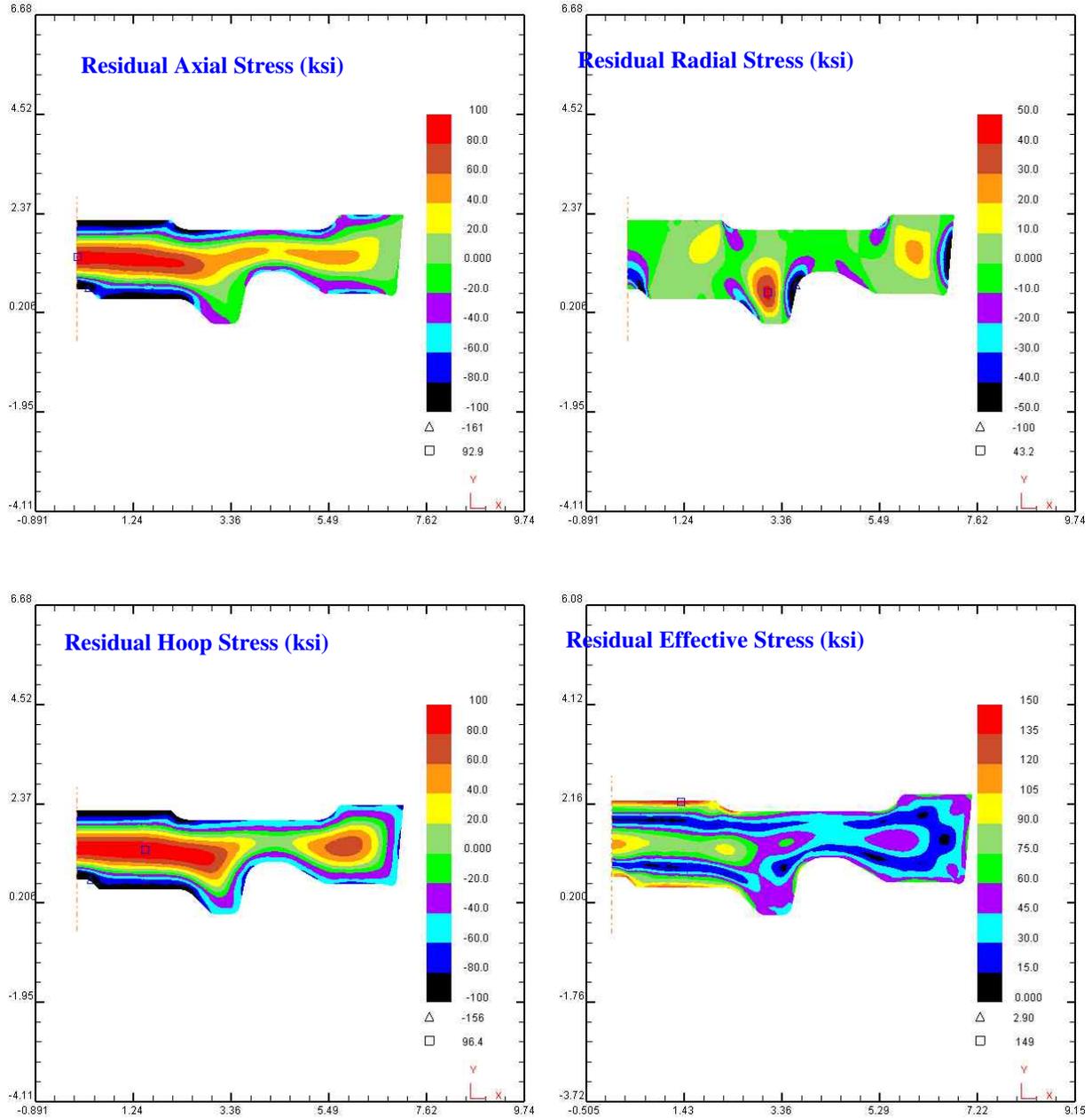


Figure 12.—Simulation; disk radial, axial, hoop and effective residual stress states.

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